COUPP Bubble Chambers for Dark Matter Detection

M. Ardid[1], E. Behnke[2], T. Benjamin[2], M. Bou-Cabo[1], S.J. Brice[3], D. Broemmelsiek[3], J.I. Collar[4], P.S. Cooper[3], M. Crisler[3], C.E. Dahl[4], J. Hall[3], C. Harnish[2], E. Grace[2], I. Levine[2], W.H. Lippincott[3], D. Maurya[5], T. Moan[2], T. Nania[2], R. Neilson[4], S. Priya[5], E. Ramberg[3], A.E. Robinson[4], A. Sonnenschein[3], E. Vázquez Jáuregui[6]

[1]Politecnica Valencia, [2]Indiana University South Bend, [3]Fermi National Accelerator Laboratory, [4]KICP, University of Chicago, [5]Virginia Tech, , [6]SNOLAB

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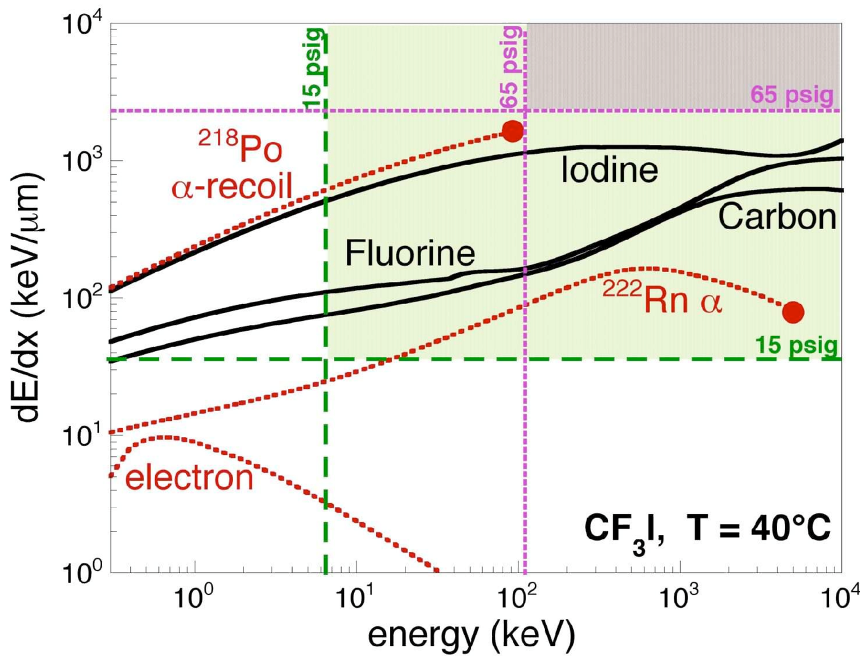
Dark Matter Detection in Bubble Chambers

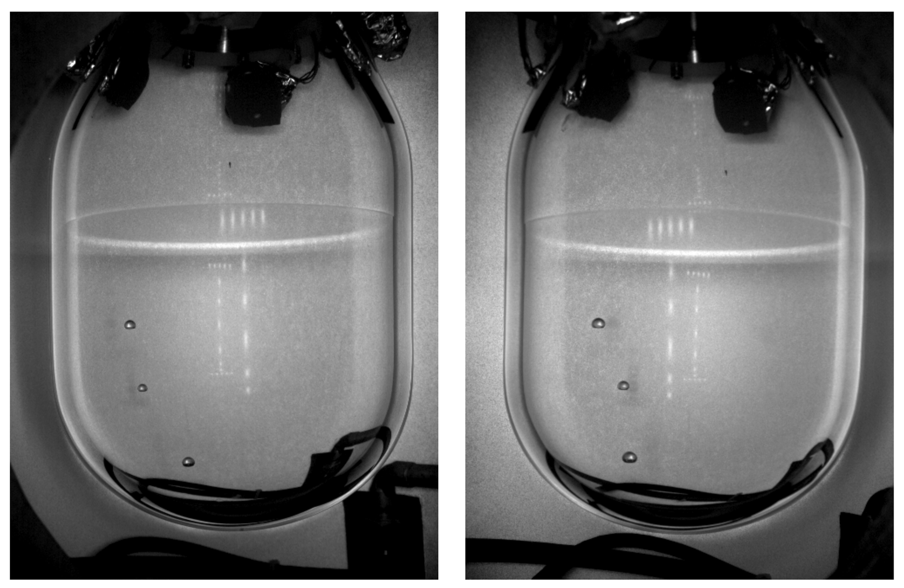
The leading dark matter candidates (WIMPs, or Weakly Interacting Massive Particles) should be detectable as they scatter off atomic nuclei in terrestrial detectors. The expected rate for these interactions is O(10^{-2}) events/kg-day or lower, so detectors must be large with low backgrounds.

Superheated fluids are thermodynamically unstable to boiling, but cannot boil spontaneously. In the absence of nucleation sites, localized excess energy from an ionizing particle is required to form the surface of the bubble (lower left).

COUPP operates bubble chambers in a thermodynamic regime sensitive to highly ionizing nuclear recoils from WIMP scatters, but completely insensitive to minimum ionizing particles, including γ's and β's. These chambers are sensitive to α's, which had been the dominant background in early COUPP detectors.



Above: Recoils in CF_3I – a recoil must be above thresholds in E and dE/dx to nucleate a bubble.



Stereo view of the first event in COUPP-4kg: a single neutron from an AmBe source nucleating three bubbles. WIMPs produce only single bubbles.

Selected Publications and References

[1] E. Behnke *et al.*, Phys. Rev. Lett. **106**, 021303 (2011).

[2] E. Behnke *et al.*, arXiv:1204.3094v1 (2012).

[3] F. Aubin *et al.*, New J. Phys. **10**, 103017 (2008).

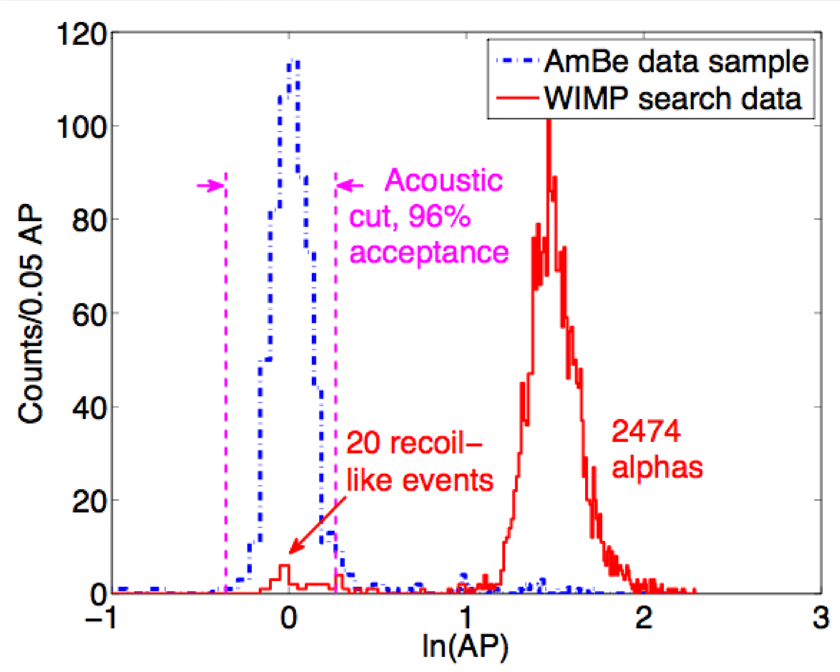
[4] F. Seitz. Phys. Fluids **1**, 2 (1958)

[5] E. Behnke *et al.*, Science **319**, 933 (2008).

Acoustic Discrimination

As a threshold detector, COUPP is unable to discriminate alpha decays by measuring their large energies. The PICASSO collaboration demonstrated the ability to distinguish nuclear recoils (WIMP scatters) from alpha decays in superheated droplets based on their acoustic signature [3].

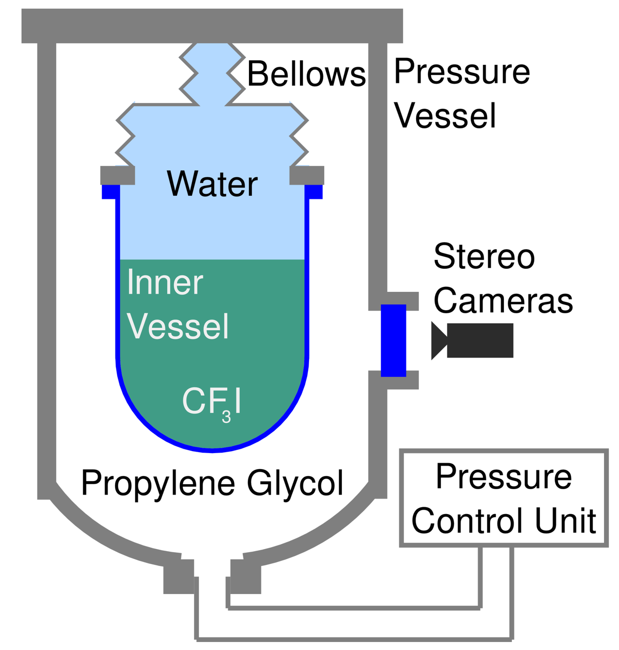
This discrimination has been confirmed by COUPP-4kg. Alpha decays are louder than nuclear recoils. Discrimination of >99% of alpha decays with 96% acceptance of nuclear recoils has been demonstrated in the 4kg chamber at SNOLAB.



The blue histogram shows a peak at ln(AP)=0 for nuclear recoils induced by a neutron source. By studying time correlations, we can identify the peak ~1.5 as bulk alpha events produced by the decay of radon.

COUPP Bubble Chambers

COUPP is a series of progressively larger, refrigerant filled bubble chambers (from 50g to a proposed 500kg device) in the hunt to directly detect dark matter. Bubbles from a nuclear recoil are measured using stereoscopic cameras, fast pressure transducers, and piezoelectric acoustic sensors, allowing for full 3-D reconstruction of the growing bubbles.

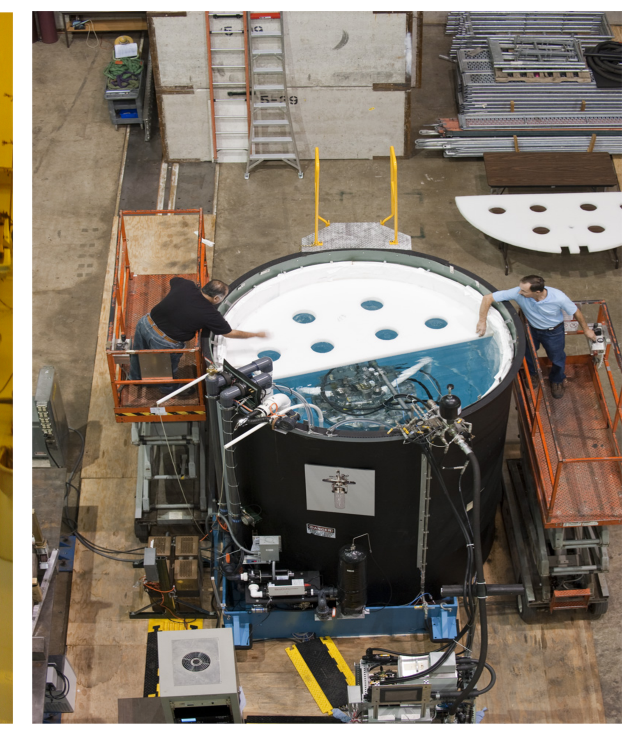


Schematic of a COUPP bubble chamber (above) and COUPP-4kg inner vessel installation (right).

COUPP-4kg has performed two dark matter searches, from 8/09 to 12/09 in the MINOS near hall 350ft underground at Fermilab [1], and from 11/10 to 6/11 at SNOLAB 6800ft underground [2]. The discovery of an internal neutron background has lead to an upgrade beginning 05/12.

COUPP-60 (right), our next generation experiment, had two engineering runs in the MINOS near hall 08/10 and 11/11, which discovered and then resolved issues with photodissociation of the CF_3I target fluid. COUPP-60 is now in the process of moving to SNOLAB, with commissioning scheduled for 09/12.

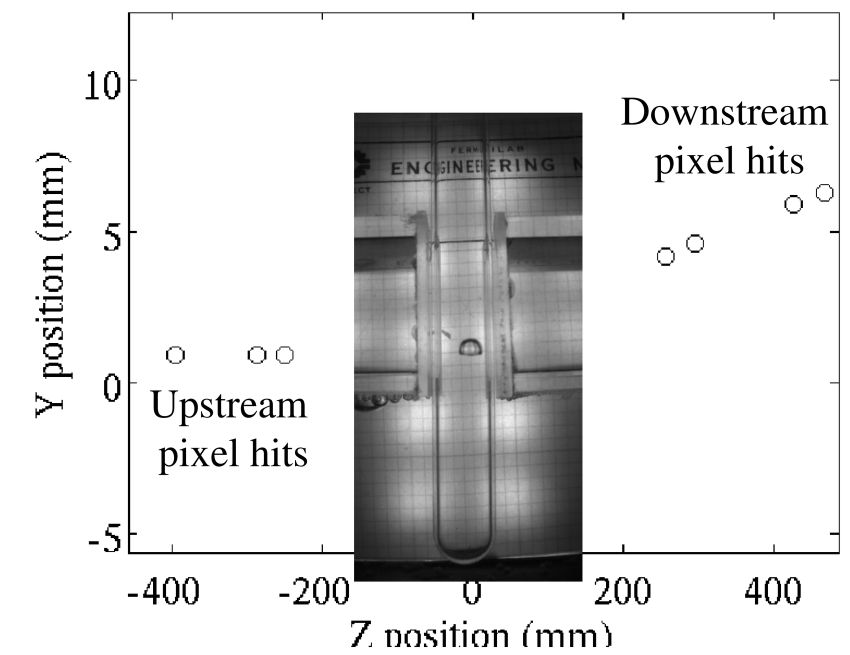
COUPP-500 is proposed for installation at SNOLAB in 2015.



Detection Efficiency

WIMP scatters will preferentially produce low energy O(10keV) nuclear recoils. COUPP's efficiency for detecting these recoils determines our WIMP sensitivity. While bubble nucleation threshold energy is calculable [4], efficiency above threshold must be measured.

A partial calibration has been obtained using high energy neutron and α sources. We have built calibration bubble chambers to measure bubble nucleation efficiencies at WIMP search threshold energies. Low energy (152keV) neutrons are used to produce carbon and fluorine recoils. As neutron induced fluorine recoils overwhelm iodine recoils, the iodine measurement uses recoils from pion scatters at Fermilab.



Above: A sample pion beam scattering event. By matching tracks with bubbles, the event-by-event energy needed to make a bubble is determined.

Latest Dark Matter Limits: from COUPP-4kg at SNOLAB 2010/11 [2]

We see 20 nuclear-recoil like events in the chamber in 637.6 kg days of exposure at three different thresholds (8, 11, 15 keV). A portion of these events is attributed to neutrons produced in the piezoelectric acoustic sensors that record the sounds of bubble formation and to the pressure vessel viewport windows. A second category of events shows anomalous timing and spatial correlations which make them poor dark matter candidates. With no background subtraction and the uncertainty in the bubble nucleation efficiency, we are able to set these limits on dark matter interactions. The blue shaded bands indicate our present uncertainty in detector efficiency.